grating of suitable ruling between the objective prism and the objective in order to obtain a spectrum photograph of a star essentially similar to that shown in fig. 2, C. It would appear that the exposures required for this purpose would not be unduly long.

The loss of light with an objective prism is very much less than when a slit spectroscope is used, and the common procedure of allowing the star to trail slowly in a direction perpendicular to the dispersion in order to widen the spectrum, is for the present purpose to be expressly avoided, with a consequent gain in brightness, the spectrum being in this case widened by the action of the grating. It is also clear that the exposure need only be of such a length as to register the faintest portions of the spectrum on the central image, the brighter portions being thus visible in the higher orders. From the expression $B_m : B = [1/m^2\pi^2] \sin^2 [am\pi/a+b]$ it follows that the brightness of the central order $B_0 : B$ will be equal to $[a/a+b]^2$, and in the case of a equal to b the exposure would only be four times as long as it would be without the grating and perhaps considerably shorter than it would be if the image of the star were allowed to trail to any considerable extent; but a smaller value of a/b would probably be necessary for the study of a number of phenomena such as the structure of the nova bands and the time of exposure would accordingly be greater.

A Superior Limit to the Age of the Earth's Crust.

By Henry Norris Russell, Professor of Astronomy in Princeton University.

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Considerations based upon radio-activity have often been employed to obtain estimates of the ages of minerals, and of the duration of geological time; but it does not appear to have been remarked that similar arguments can be used to assign a maximum age for the existing crust of the Earth.

Uranium is continually disintegrating with a "half period" of 5×10^9 years, and no process is known by which the supply can be renewed. It is probable that the proportion of this element in the Earth's crust was greater formerly than at present—the computed amount necessary to account for the survival of that which now exists increasing exponentially with the time interval, a thousand fold in ten half periods and a million fold in twenty.

The existing proportion of uranium may be derived from that of radium, which, according to Joly,[*] averages about $2{\cdot}5 \times 10^{-12}$ parts by weight. The equilibrium ratio of uranium to radium is $3{\cdot}1 \times 10^{6}$, and the proportion of uranium in the Earth's crust may therefore be estimated as 7×10^{-6}. If the whole crust had been originally composed of uranium, it would have decayed to the present proportion in seventeen half periods, or $8{\cdot}5 \times 10^{10}$ years. But this assumption would lead to the absurd conclusion that the crust must now be composed entirely of the products of radio-active disintegration of the original uranium.

The end-product of the uranium series is an isotope of lead, which appears to be stable. Now the proportion of lead in the Earth's crust is small, amounting, according to Clarke,[†] to 22×10^{-6} by weight. If this were all "uranium lead," it would result from the decay of 25×10^{-6} parts of uranium, making the initial content of the latter 32×10^{-6}, and leading to an age of 2·1 half periods, or 11×10^{9} years. Since much, if not most, of the existing lead consists of other isotopes, this estimate must be too great.

This limit may be reduced by taking account of thorium, which, according to Joly,[‡] occurs in igneous rocks in the average proportion of 2×10^{-5}. Assuming the stability of thorium lead, and taking the half period of thorium as $1{\cdot}3 \times 10^{10}$ years, it is found that the amount of lead produced by the decay of thorium during the past 8×10^{9} years, should be 10×10^{-6} of the whole mass of the crust. The decay of uranium during the same interval accounts for 12×10^{-6}, and the sum of these two reproduces Clarke's estimate of the total lead. It is of interest to note that the average atomic weight of such a mixture would be about 206·9—near that of ordinary lead, though a little low.

If uranium lead should prove to be unstable, these calculations would require revision; but the combined proportion of all the elements of atomic weight greater than 100 in the Earth's crust amounts to hardly more than one part in a thousand, according to Clarke, and almost all this is barium. On the extravagant assumption that all these elements are disintegration products, the computed age comes out $3{\cdot}5 \times 10^{10}$ years. This must be far too great. These conclusions are invalid if uranium is being formed in the Earth's crust. Building up of heavier out of lighter atoms appears to be exceedingly improbable under terrestrial conditions. The existence of a "parent" of uranium, of greater atomic weight and longer life, would meet the requirement; but such an element would have to be much more abundant than uranium, and it seems very unlikely that it would have escaped detection.

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[*] 'Philosophical Magazine,' Series 6, vol. 24, p. 700 (1912).

[†] "Data of Geochemistry," p. 29, 'Bulletin, 695, United States Geological Survey,' Washington (1920).

[‡] *Loc. cit.*, p. 701.

There appears, therefore, to be little escape from the conclusion that the Earth's crust cannot have existed as such for so long as 3×10^{10} years, and that its age is probably much less. On the other hand, Barrell,* following Arthur Holmes in a discussion of the uranium-lead ratios in primary minerals, finds that minerals of Middle Pre-Cambrian Age, from localities as widely separated as Canada, Texas, Norway, and Africa, agree in indicating an age of about $1{\cdot}1 \times 10^9$ years. The age of the Earth's crust must be considerably greater.

Taking the mean of this and the upper limit found above from the ratio of uranium to lead, we obtain 4×10^9 years as a rough approximation to the age of the Earth's crust. The radio-active data alone indicate that this estimate is very unlikely to be in error in either direction by a factor as great as three. Indeed, it might be safe to say that the age of the crust is probably between two and eight thousand millions of years.

Upon the tidal (or planetesimal) theory of the origin of the Solar system (which at present appears the most probable),† this would be identified with the interval since the encounter which led to the ejection from the Sun of the material which formed the planets. It is then possible to postulate an origin for the terrestrial uranium, either in some heavier parent element, now confined to the denser interior portions of the Earth and Sun, or in the synthesis of heavy atoms under the extreme conditions which prevail in the Sun's interior—provided that we wish to extend our speculations so far.

It is of much interest that H. Jeffreys, from entirely different data, relating to the eccentricities of the present orbits of the planets, estimates the age of the solar system as 3×10^9 years. The agreement with the present result is far within the uncertainty of the estimates.

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* 'Bulletin of the Geological Society of America,' vol. 28, p. 880 (1917).

† See H. Jeffreys, 'Monthly Notices of the Royal Astronomical Society,' vol. 78, pp. 424–441 (1918).